

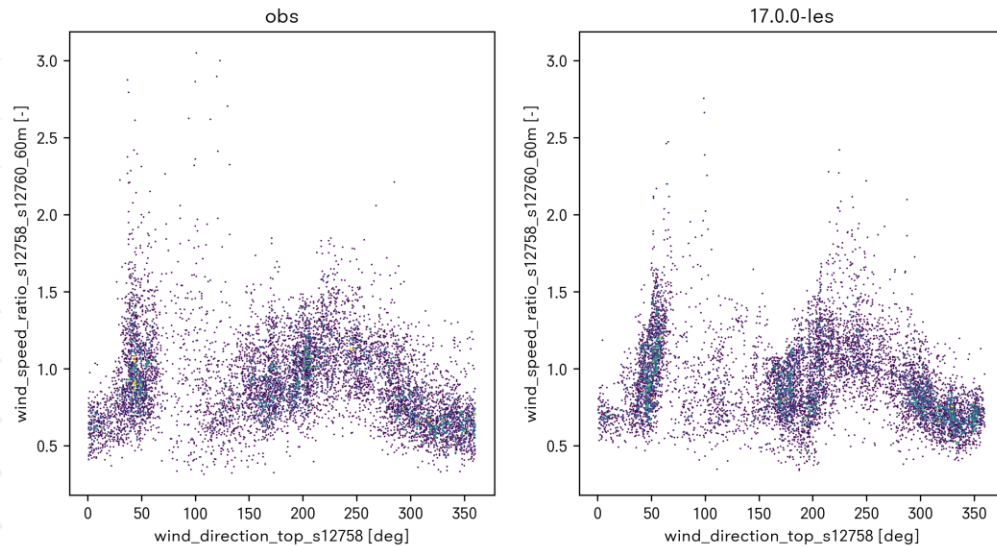


# Cross-prediction of wind and turbulence using Whiffle LES

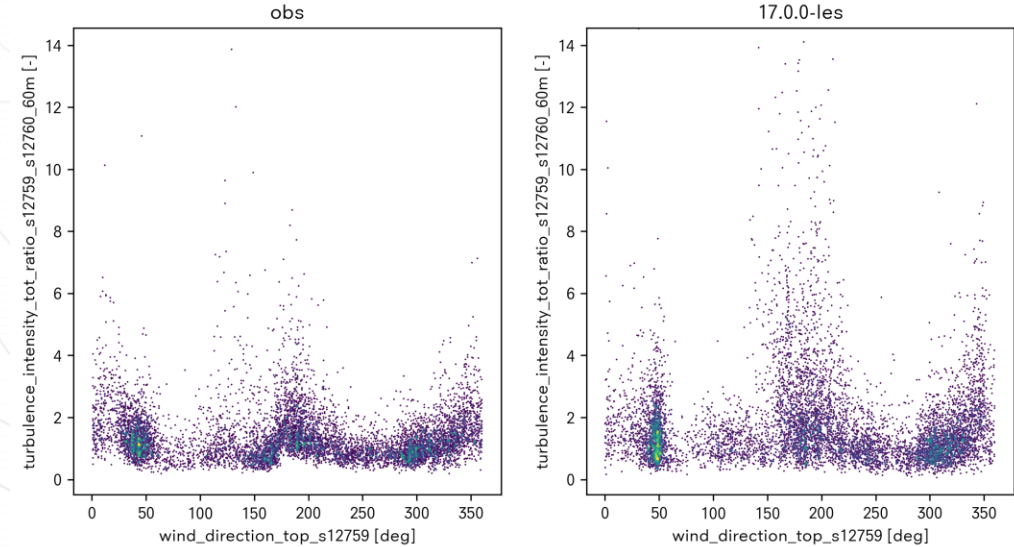
# Example cross-prediction in complex terrain

Whiffle LES provides fully time-correlated wind speed and turbulence (cross) predictions.

## Wind speed



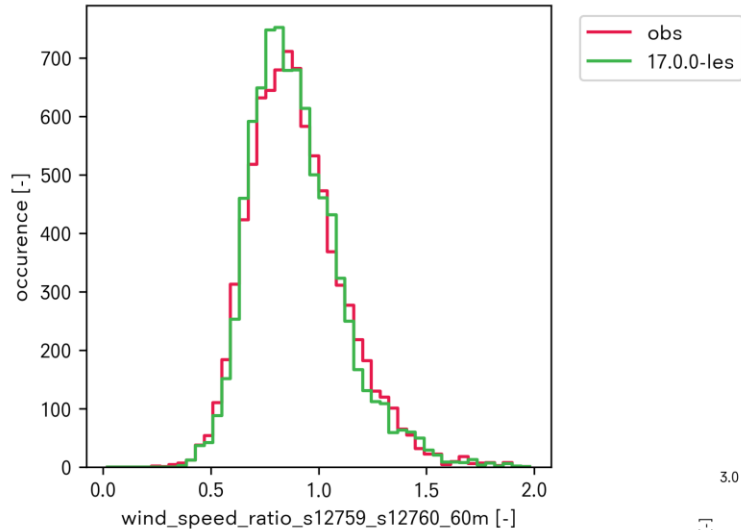
## Turbulence intensity



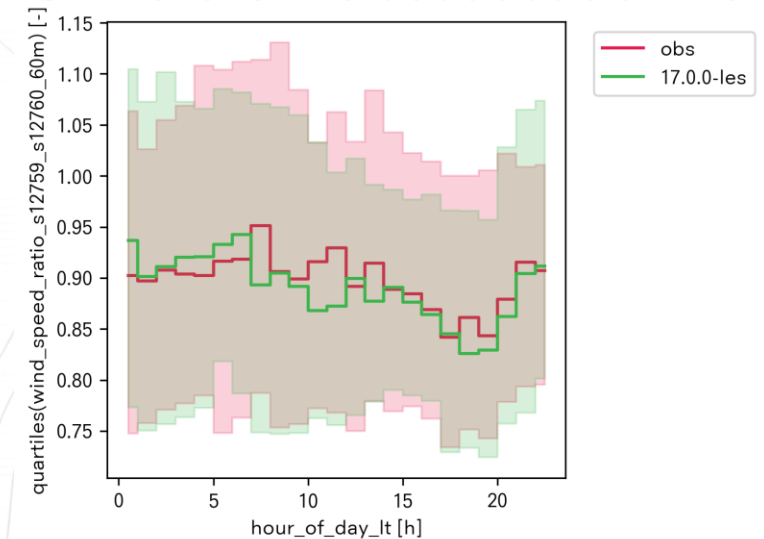
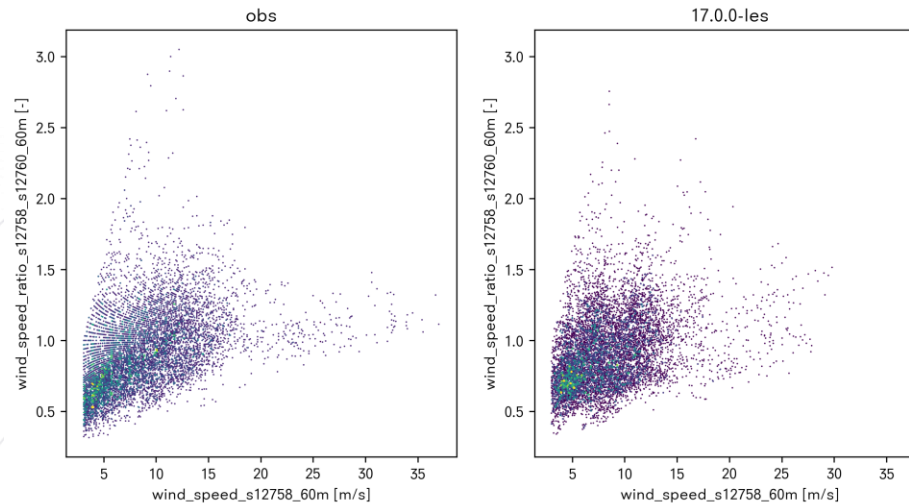
Every point indicates one 10 min average wind speed ratio vs. the mean wind direction in that interval. Whiffle LES captures observed distribution of wind speed and turbulence intensity ratios.

# Example cross-prediction in complex terrain

Whiffle LES provides fully time-correlated wind speed and turbulence (cross) predictions.



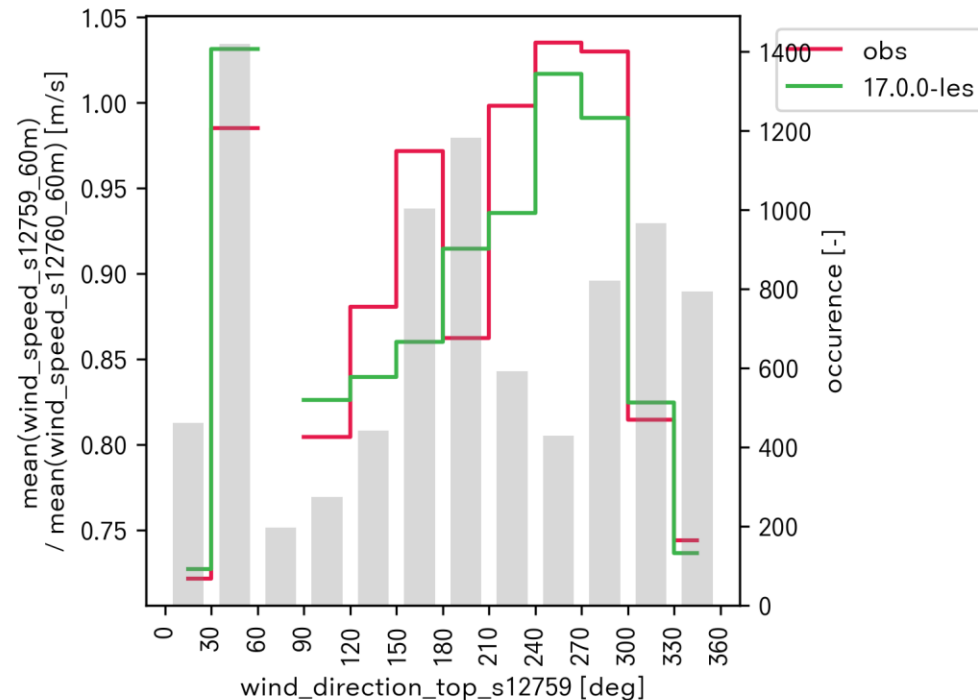
In addition to the wind direction dependence, Whiffle LES provides insight in the full distribution of wind speed and turbulence intensity ratios, including their dependence on wind speed, hour of day, etc.



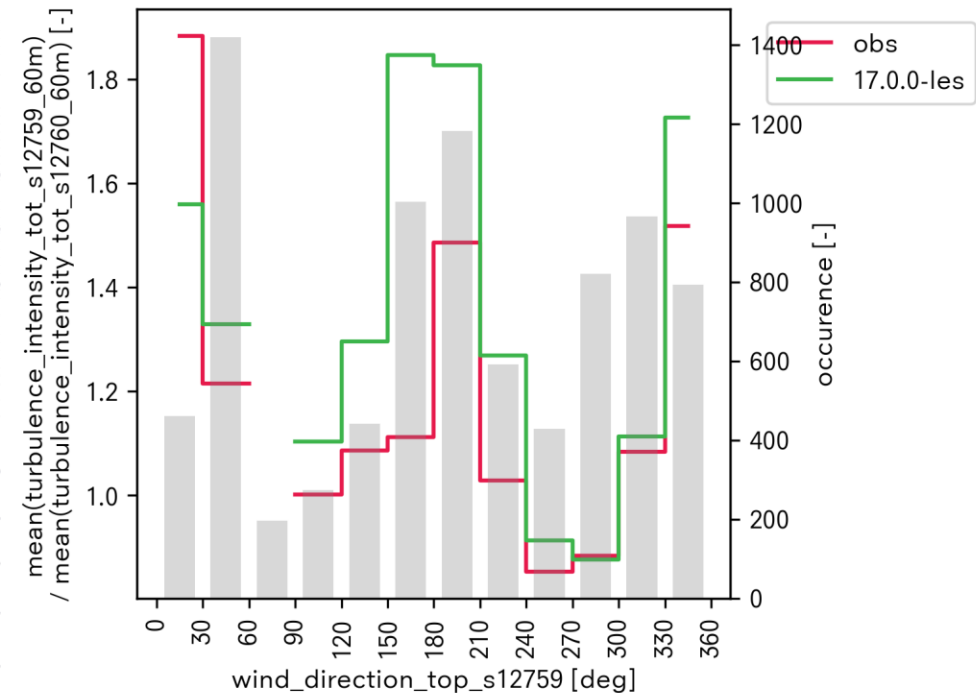
# Example cross-prediction in complex terrain

For comparison with more traditional tools like WaSP and RANS-CFD, the time series output are reduced to sectorial mean wind speed (and turbulence intensity in the case of LES) and the sectorial mean ratios can be calculated. From this, cross-prediction accuracy can be quantified by the sectorial weighted mean percentage error (WMPE) and the sectorial weighted mean absolute percentage error (WMAPE) metrics.

### Wind speed



### Turbulence intensity



# Aggregated cross-prediction validation

At every new major release of Whiffle's weather model, the accuracy is validated at around 50 sites around the globe of varying complexity and atmospheric conditions.

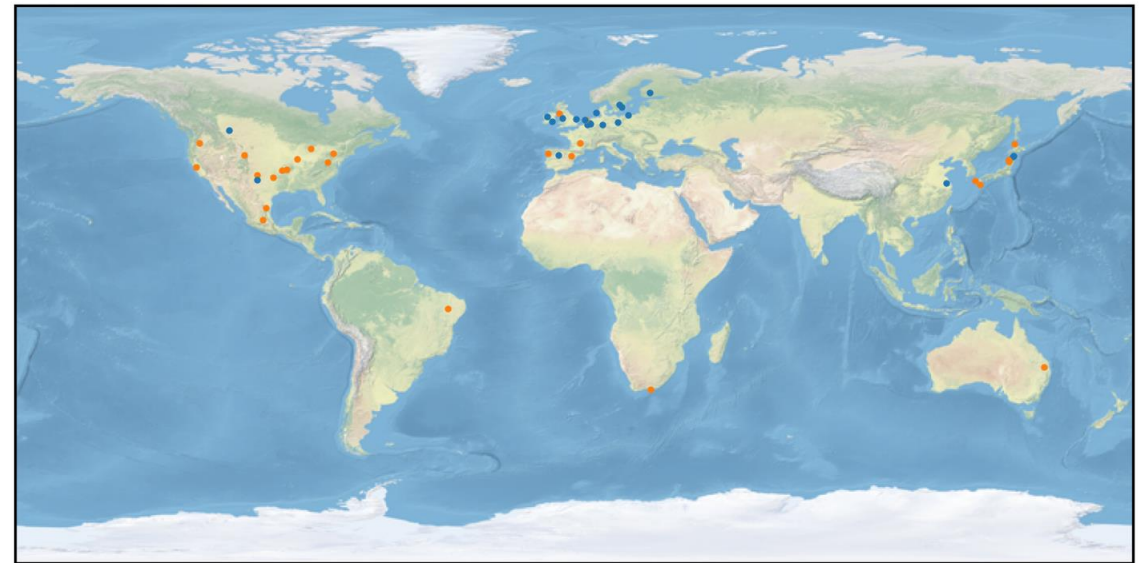
Whiffle's LES-based weather model is turbulence resolving, providing predictions of both wind speed and turbulence.

Around 20 of the validation sites have multiple measurement locations for validation of cross-prediction of the model.

Cross-prediction accuracy is assessed by the sectorial weighted mean percentage error (WMPE) and the sectorial weighted mean absolute percentage error (WMAPE) metrics.

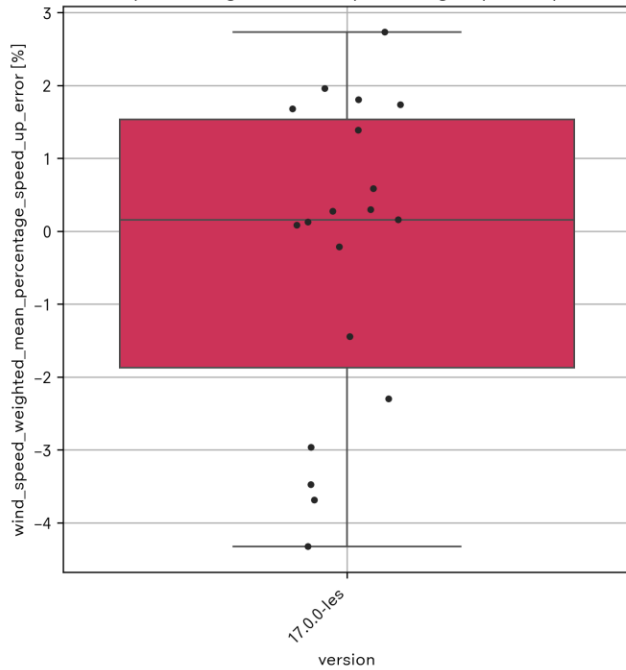
Timestamps are included if wind speed  $> 3$  m/s.

● Single measurement      ● Multiple measurements

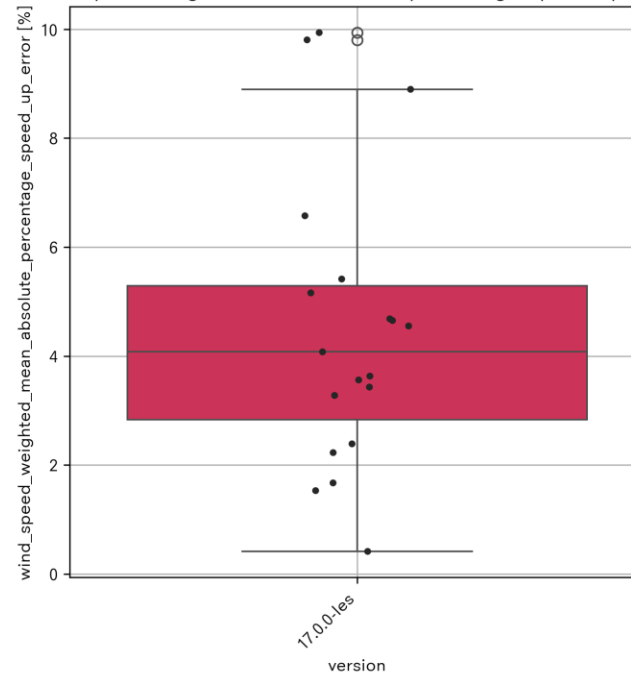


# Wind speed cross-prediction

mean of wind\_speed\_weighted\_mean\_percentage\_speed\_up\_error over site



mean of wind\_speed\_weighted\_mean\_absolute\_percentage\_speed\_up\_error over site

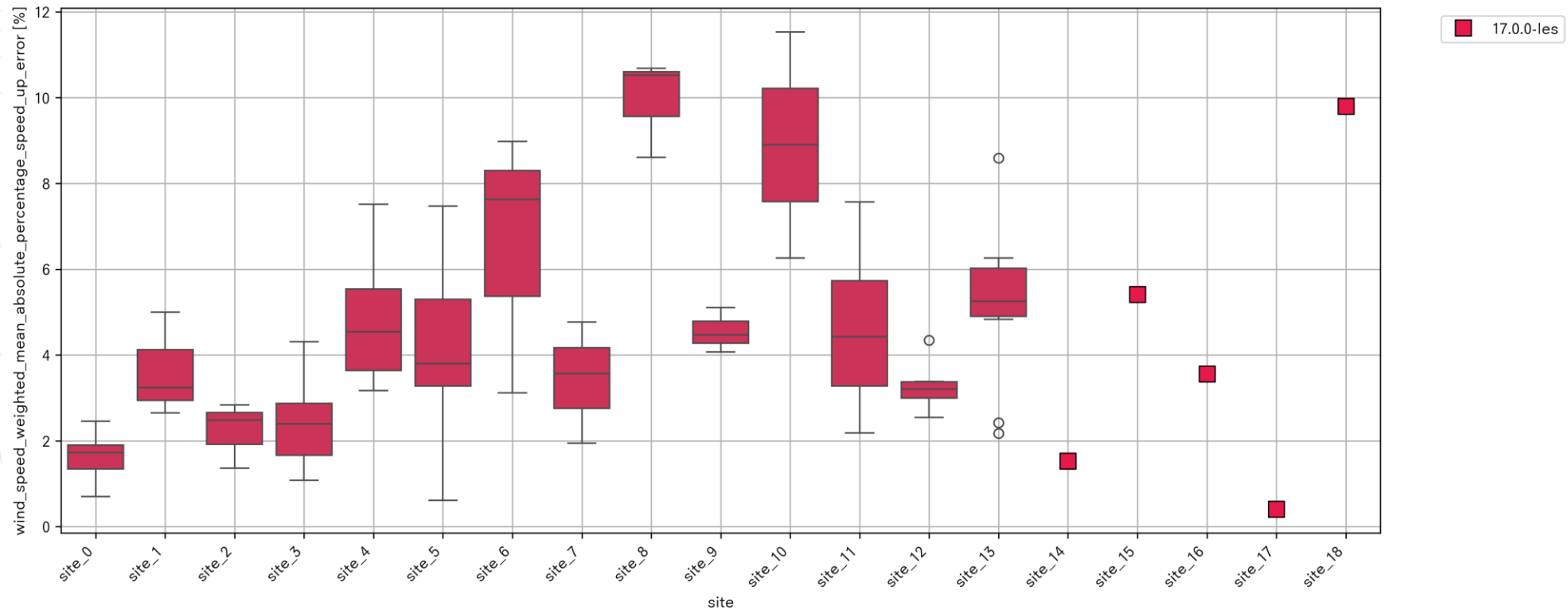


The sectorial WMPE for wind speed cross prediction is accurate within 1-2% for most sites, with some higher values for very complex sites.

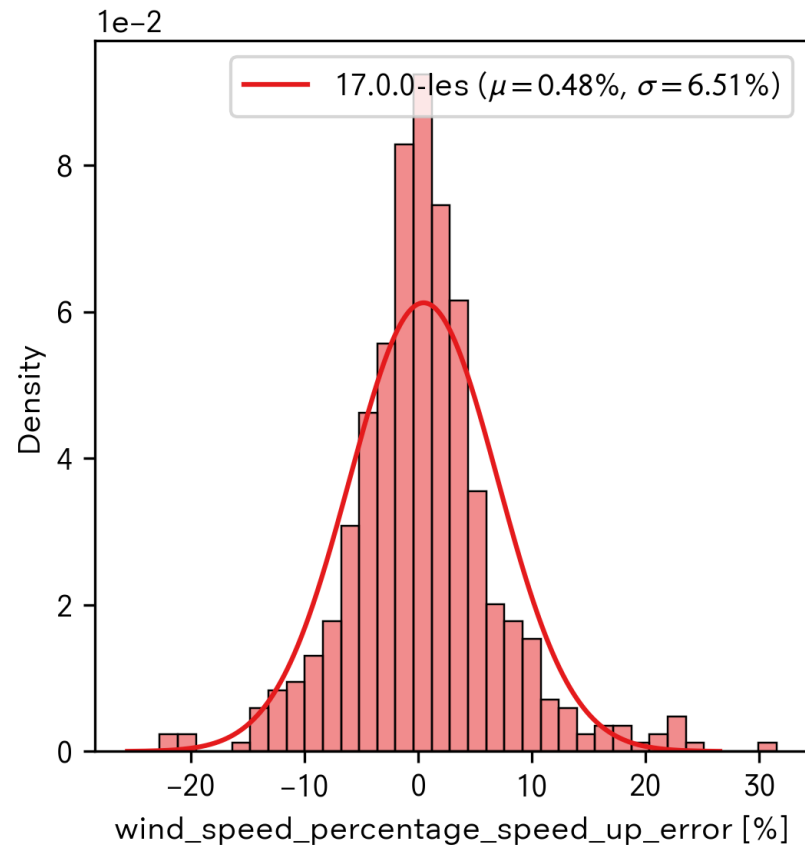
The sectorial WMAPE is around 4% with lower values for non-complex sites and higher values for very complex sites.

# Wind speed cross-prediction by site

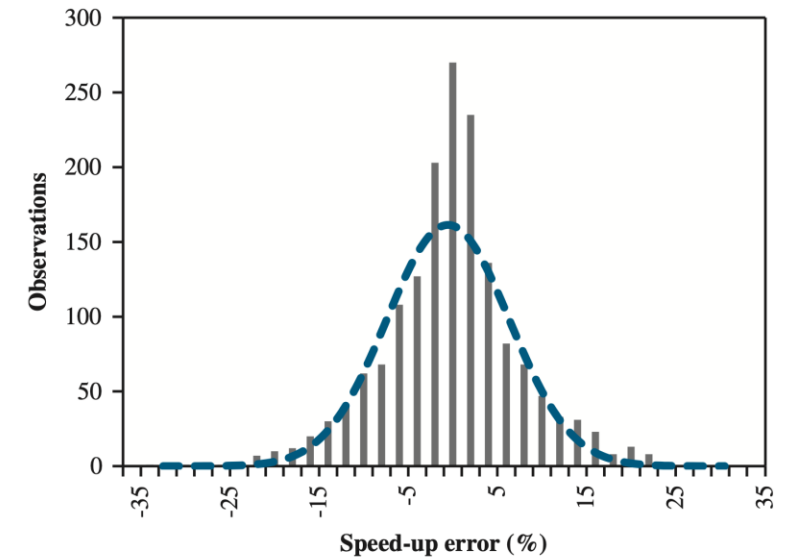
The WMAPE split by site gives insight in the spread of cross prediction accuracy for different measurement locations pairs within one site, and the spread between sites.



# Wind speed cross prediction by sector

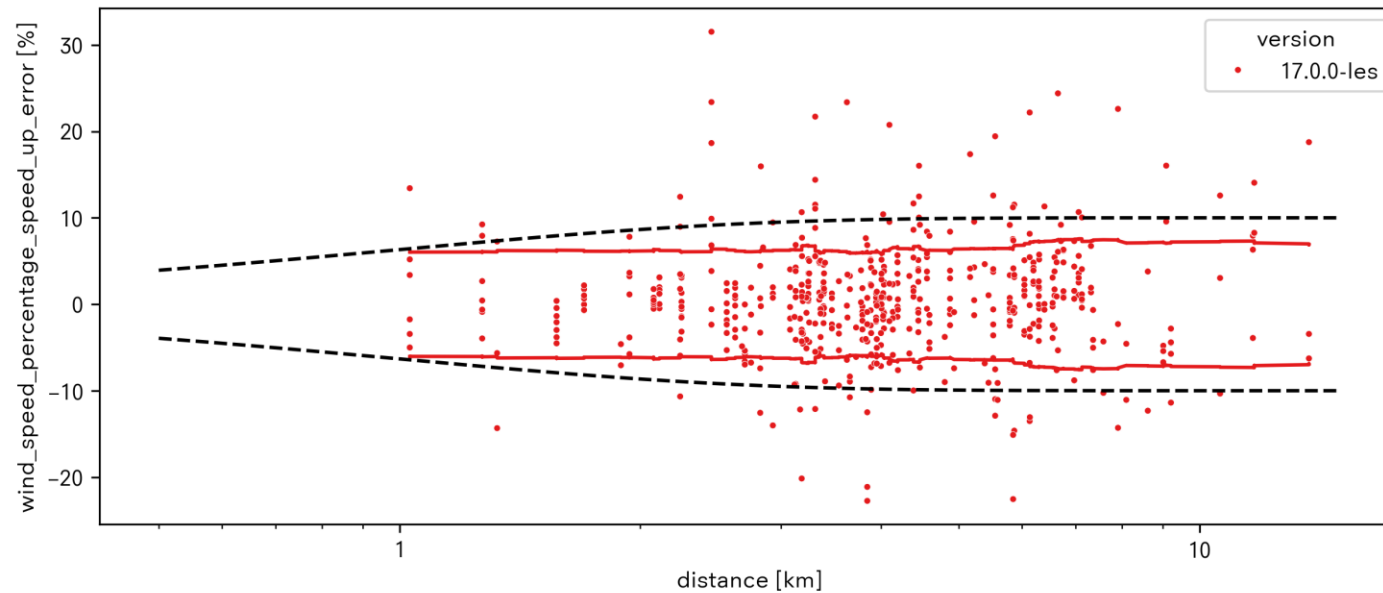


The wind speed cross prediction can also be considered per sector, per location pair as in Clerc (2012). Standard deviation is around 6.5%. Clerc (2012) report a standard deviation of 7.6% for their validation suite.

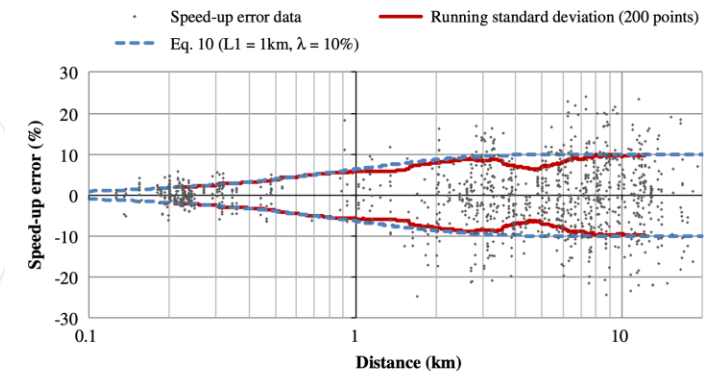


Clerc, Alex, et al. "A systematic method for quantifying wind flow modelling uncertainty in wind resource assessment." *Journal of Wind Engineering and Industrial Aerodynamics* 111 (2012): 85-94.

# Wind speed cross prediction by distance

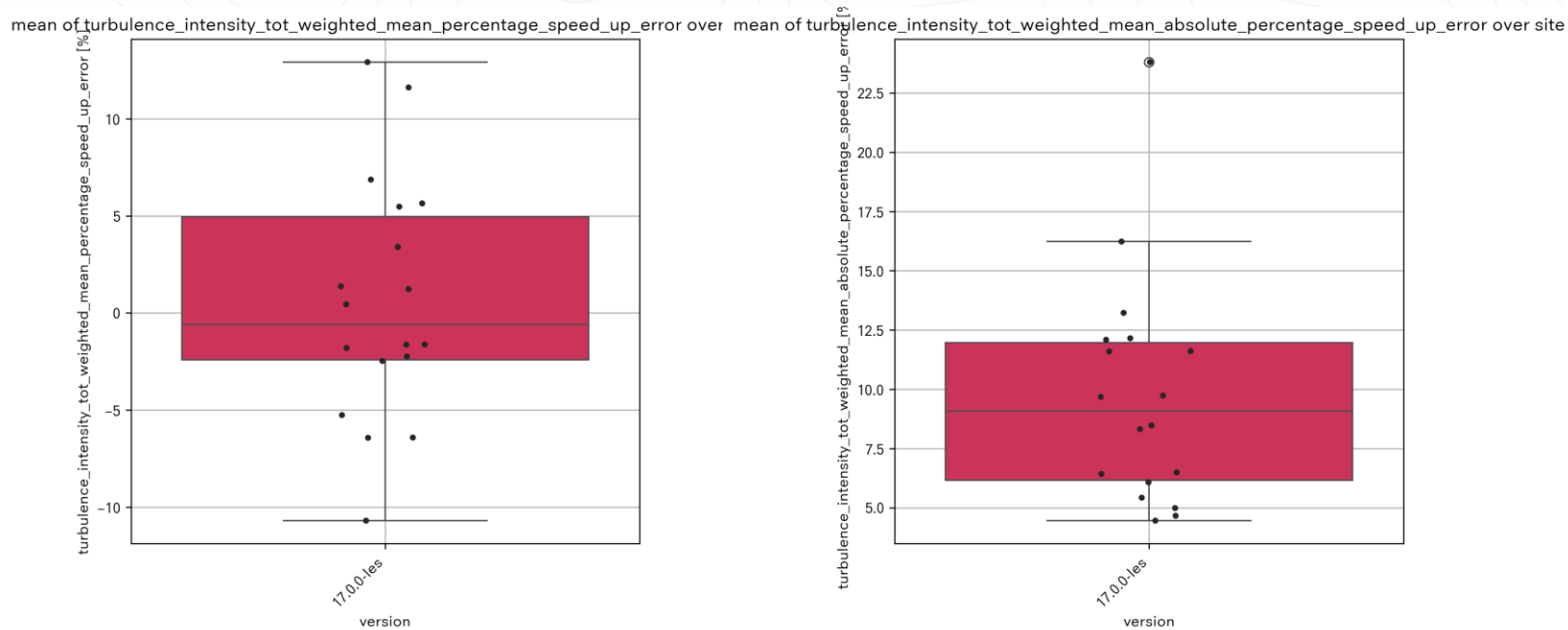


Clerc (2012) also report the speed-up error by distance between location pairs, and report a fit to the standard deviation by distance (black dashed line in figure to the left). Whiffle LES shows a somewhat tighter spread indicating lower errors on average, but the validation suites are not one-to-one comparable.



Clerc, Alex, et al. "A systematic method for quantifying wind flow modelling uncertainty in wind resource assessment." *Journal of Wind Engineering and Industrial Aerodynamics* 111 (2012): 85-94.

# Turbulence intensity cross-prediction



Accurate (cross) prediction of turbulence intensity (TI) requires both wind speed and wind speed standard deviation to be accurately modelled. Whiffle LES typically captures the sectorial weighted mean TI within 5%. The sectorial WMAPE is around 10%.